Focused session: Material synthesis and condensed matter physics

Paul Evans, Haidan Wen, John Freeland, Oleg Shpyrko, Darrell Schlom,
and all attendees

Recap of the session “Materials Synthesis & Condensed Matter”

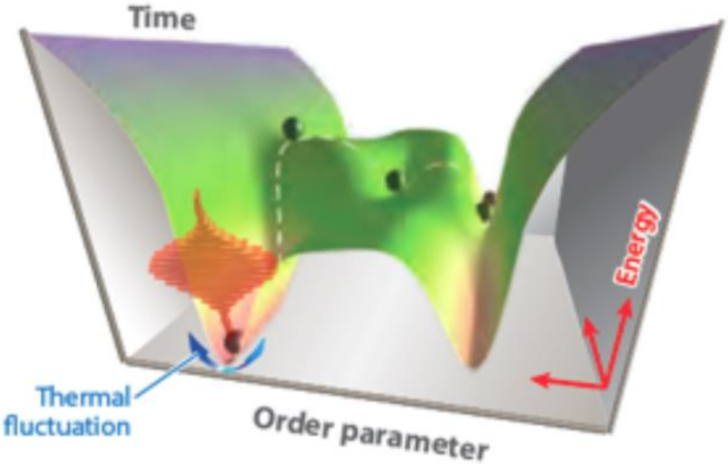
- Oleg Shpyrko: *“Coherent X-ray Nano-vision”*
- Darrell Schlom: *“Establishing how oxide films grow: An essential part of the materials by design dream”*
- John Freeland: *“Summary from “Frontier experiments in condensed matter physics”*

- Open floor discussion: Hua Zhou, Jessica McChesney, Jungho kim, Yi Zhu, Ian McNulty,…

Complexity in Condensed Matter

Non-equilibrium
(100 ps to s)

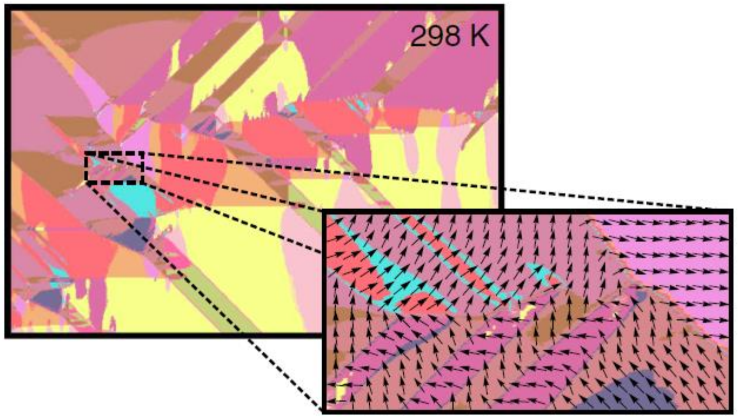
e.g. Optical Excitation



R. Averitt (UCSD)

Non-homogeneous
(10 nm to mm)

e.g. BaTiO3 phases



V. Gopalan (PSU)

Credit to John Freeland

Science drivers

- **Discovering materials with novel properties**: precision synthesis, defects control, ionic transport, vacancy kinetics, interface engineering

- **Understanding phase competition and fluctuation**: emergent correlation and functionalities, fluctuation at critical points

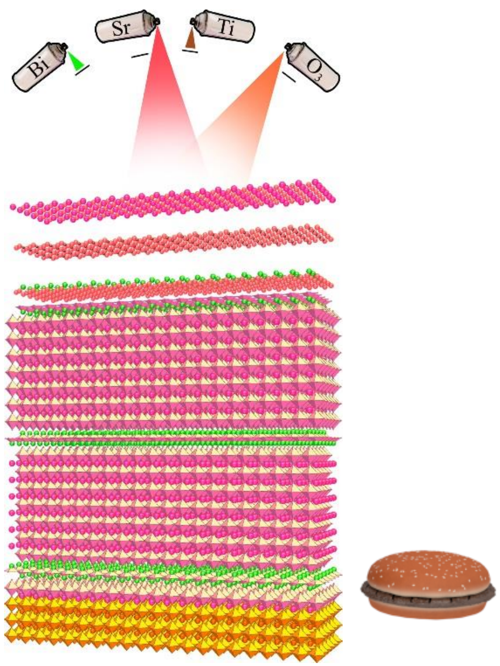
- **Controlling collective energy conversion and transport**: collective excitations such as polarons, magnons, skyrmions, CDW, SDW, coupling of multiple degrees of freedom

Examples

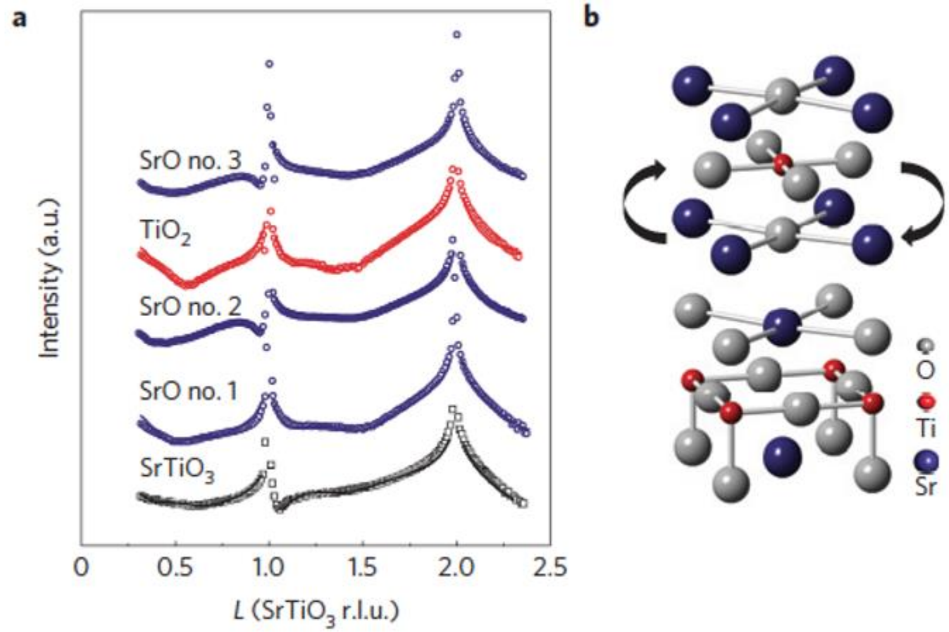
Oxides with hidden properties

Control tool boxes:

- Dimensional Confinement
- Strain Engineering
- Polarization Doping
- Interface Engineering
- Epitaxial Stabilization



However, growth does not follow cartoon!



J.H. Lee et al., Nature Materials, 13 879 (2014)

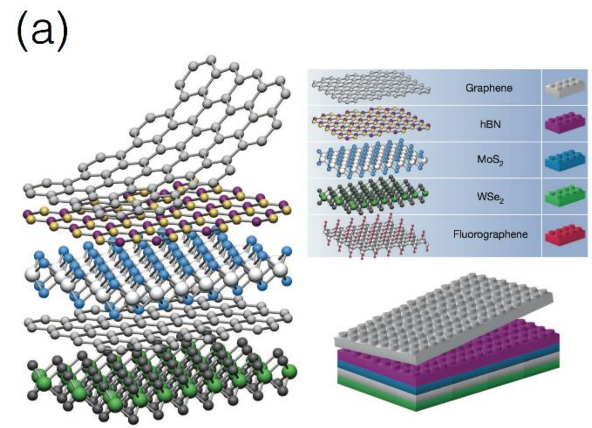
Require in-situ characterization!

Credit to Darrell Schlom

Surface and Interface Dynamics in Thin Film Materials Synthesis

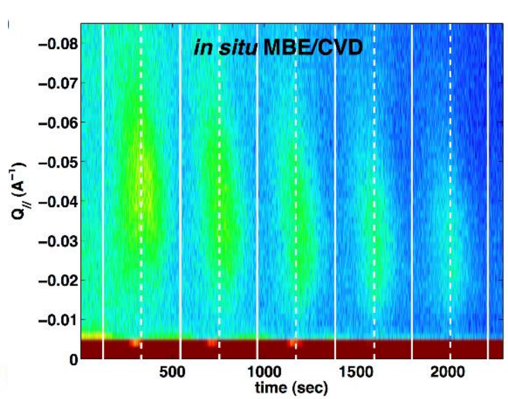
Credit to Dillon Fong

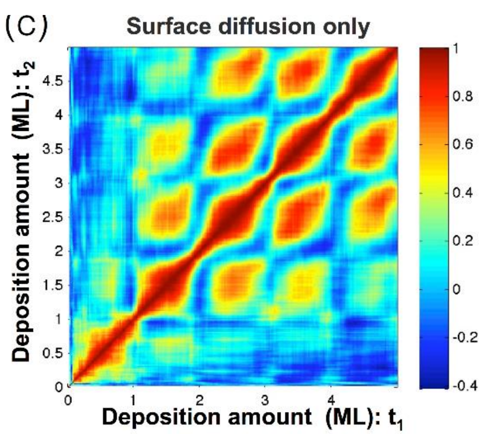
- ## Science Challenge/Opportunity
  - Interfaces and heterostructure *design* is rapidly advancing
    - 2D electronic materials
    - Polar/magnetic/superconducting complex oxide
  - Synthesizing these important electronic materials remains challenging because many surface/interface phenomena are unknown.
- ## Diffraction-limited storage ring strengths & challenges
  - Coherence techniques probe isolated events within quasi-continuous processes: microscopy, ptychography, XPCS

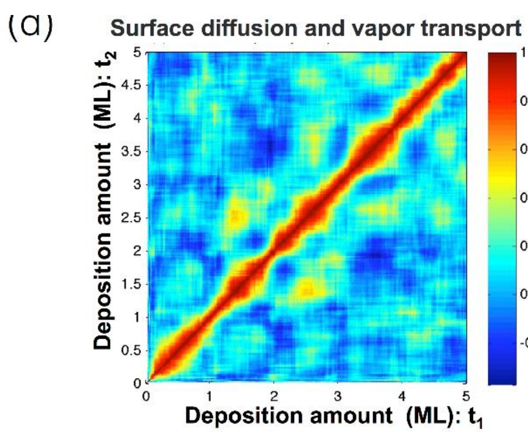


2D electronic materials: stacking

Oxide heterostructures: MBE/CVD/PLD, island formation, atomic/molecular transport







Dynamic and Meso-COBRA

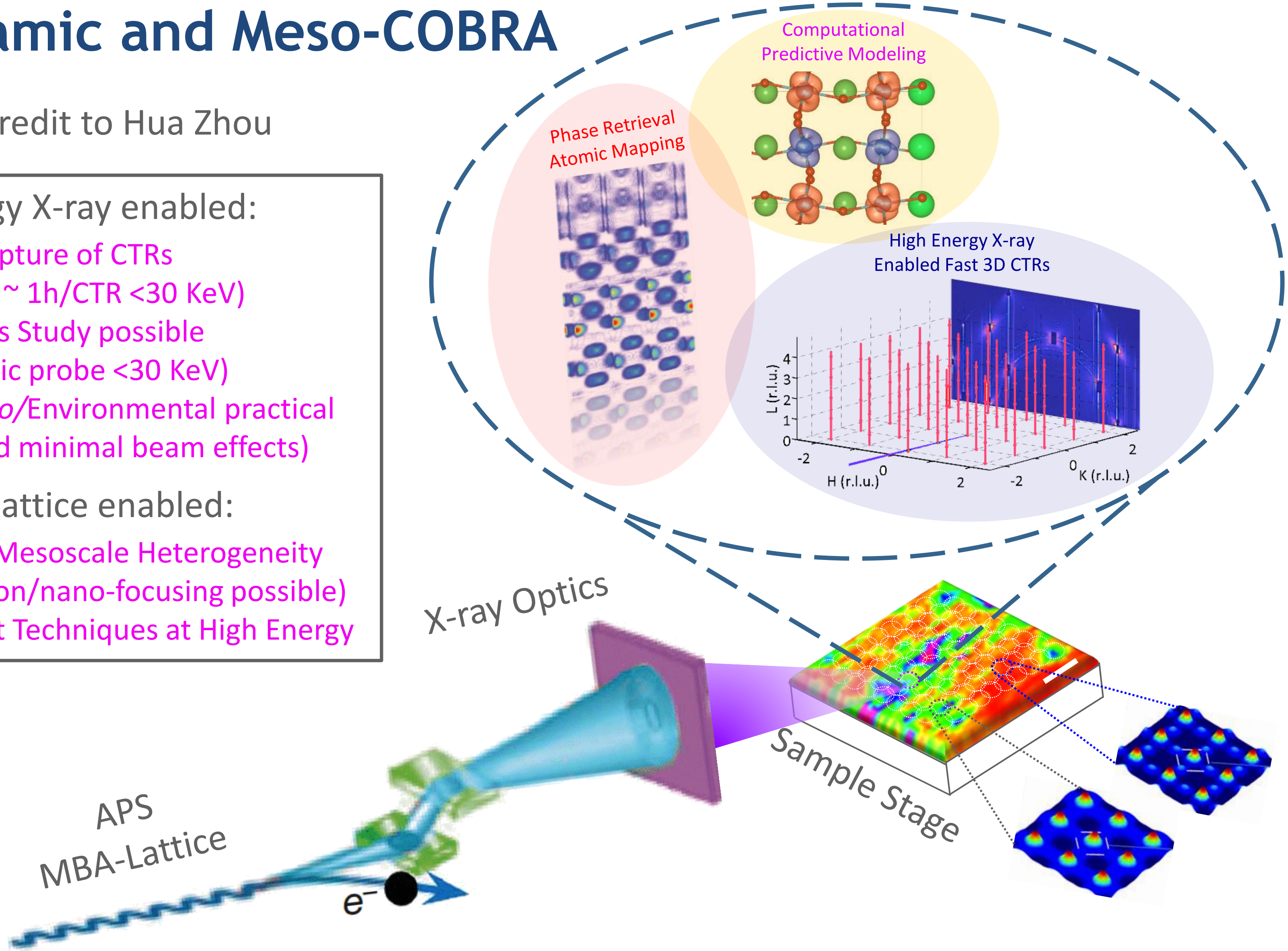
Credit to Hua Zhou

High Energy X-ray enabled:

- ✧ Rapid Capture of CTRs (3-5 s Vs. ~ 1h/CTR <30 KeV)
- ✧ Dynamics Study possible (only static probe <30 KeV)
- ✧ *Operando/*Environmental practical (deep and minimal beam effects)

APS MBA-lattice enabled:

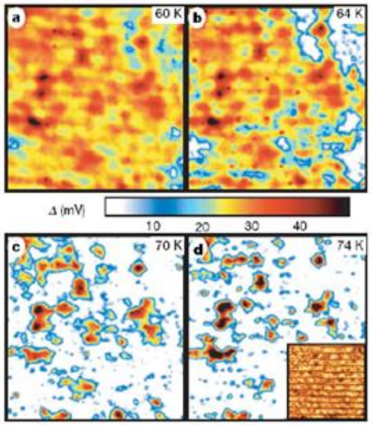
- ✧ Probing Mesoscale Heterogeneity (submicron/nano-focusing possible)
- ✧ Coherent Techniques at High Energy



Multiscale X-ray Probe for Mapping Dynamics and Heterogeneity at Reduced Dimensions

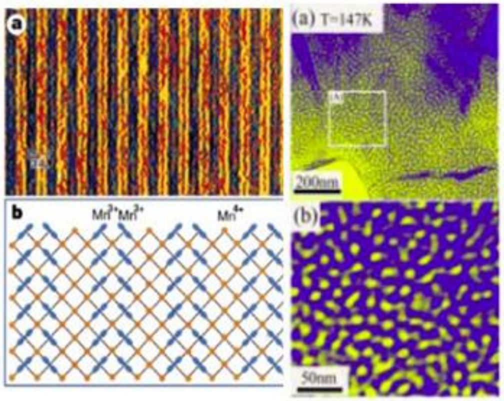
Imaging phase separation and collective excitation

High-Tc cuprates



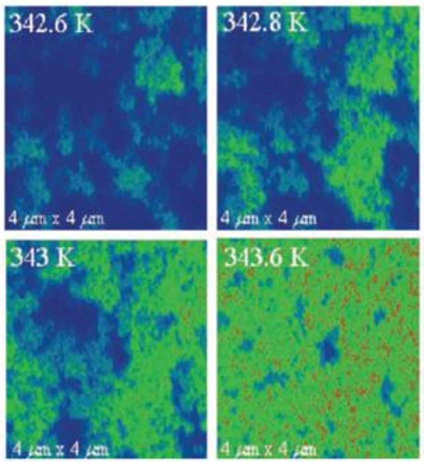
Gomes et al.,
Nature 447, 569 (2007)
SC Gap in BSCCO
(Yazdani Group, Princeton)

CMR manganites

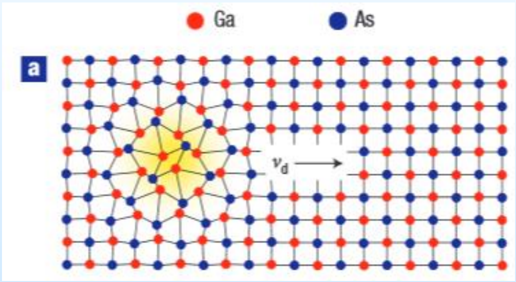


S. Mori et al., *Nature* **392**, 473 (1998)
M. Uehara et al., *Nature* **399**, 560 (1999)

Metal-Insulator Transition In VO2

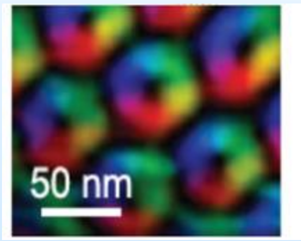


Qazilbash et al.,
Science 318, 1750 (2007)
Metal-Insulator Transition in VO2 (Basov Group, UCSD)



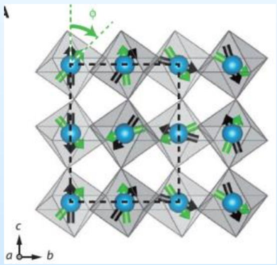
Polaron

Gaal, et al. Nature 450, 1210 (2007)



Skyrmion

Seki, et al. Science 336, 198 (2012)



electromagnon

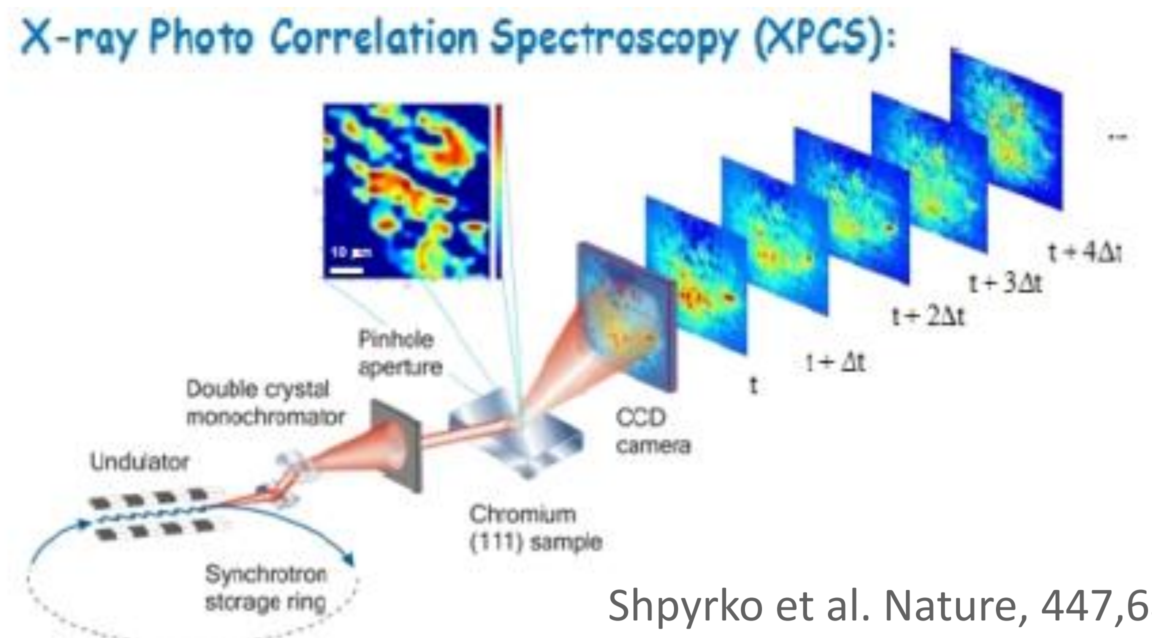
Kubacka, et al. Science, 343, 1333 (2014)

Fluctuations

Electronic, magnetic, structural and quantum fluctuations

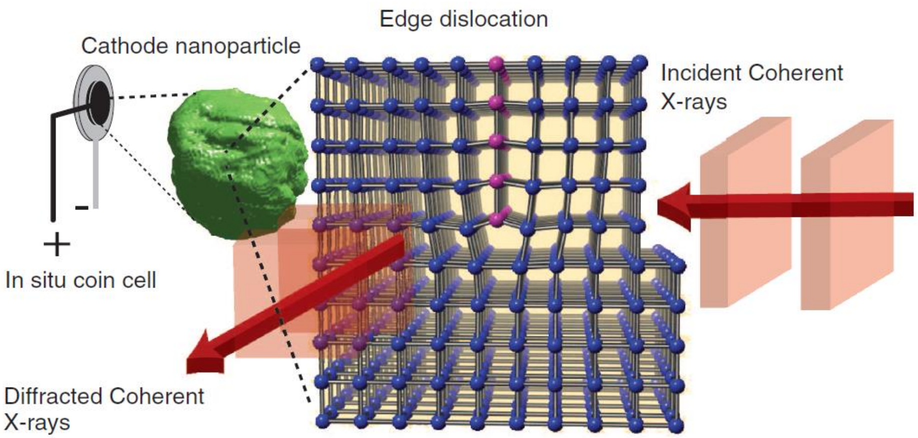
Accessible time scale of XPCS with the APS-U

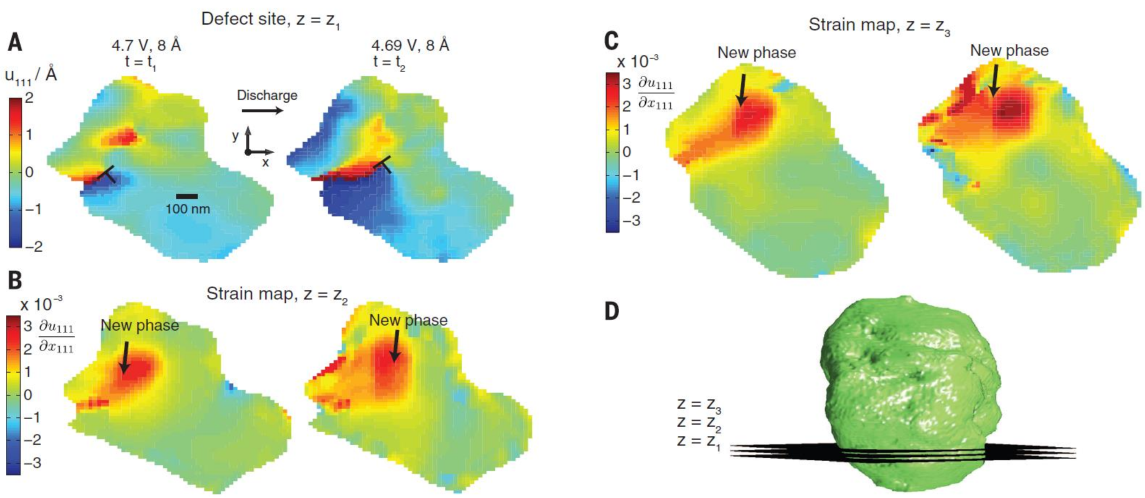
sub-μs



Shpyrko et al. Nature, 447,68 (2007)

Imaging defects: *in-situ in-operando*





Ulvestad, et al. Science, 348, 1344 (2015)

Nonequilibrium dynamics

Mesoscopic structural phase progression in photo-excited VO_2

Data not shown

APS-U: From time-resolved scanning microscopy to coherent imaging

- Alleviate beam damage
- Better spatial resolution (300 -> 30nm)
- 3D imaging

Technical advances with APS-U

High Energy

- ***In-situ in-operando* coherent imaging**: energy transport, defects
- **Materials at extreme conditions**: high P and T
- **Larger Q**: High-speed COBRA

Coherence

- **XPCS with enhanced coherence**: fluctuation at ns time scales
- **Coherent diffraction imaging:** defects, in-situ 3D imaging, ultimate limit: 2D: 2 nm, 3D: 4nm
- **Nano-APRPES, Nano-RIXS, Nano-XAS**…: local properties at nm length scales
- **Pump-probe coherent imaging**: nonequilibrium states of heterogeneities.